TECHNICAL NOTE

D-975

LANDING-IMPACT-DISSIPATION SYSTEMS

By Lloyd J. Fisher, Jr.

Langley Research Center
Langley Air Force Base, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TECHNICAL NOTE D-975

LANDING-IMPACT-DISSIPATION SYSTEMS*

By Lloyd J. Fisher, Jr.

SUMMARY

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Analytical and experimental investigations have been made to determine the landing-energy-dissipation characteristics for several types of earth-landing-impact systems having application to reentry vehicles. The areas of study are divided into three velocity regions: (1) those having primarily vertical velocity, (2) those having both moderate horizontal and moderate vertical velocity, and (3) those having primarily horizontal velocity. The impact systems discussed are braking rockets, gas-filled bags, frangible metal tubing, aluminum honeycomb, balsa wood, strain straps, and both skid and skid-rocker landings on hard-surface runways and on water.

It appears feasible to evaluate landing-gear systems for reentry vehicles by computational methods and free-body landing techniques with dynamic models. There are several ways of dealing with the vertical energy dissipation for an earth landing of such a vehicle. Some systems are more efficient than others, some package better than others, and a variety of promising systems are under study. Horizontal energy dissipation is simpler to deal with than vertical energy dissipation since translational friction is all that is involved; however, runout behavior becomes a factor. Vertical velocity can also be a big factor when high flight-path angles are associated with even moderate horizontal velocities. High-speed landings are particularly a problem, especially high-speed water landings, and indications are that if large horizontal velocities are involved in hard-surface landings, a selected site will be required.

INTRODUCTION

The approach parameters for letdown systems having application to reentry vehicles are found to divide the landing-energy-dissipation problem into three velocity regions. This paper is concerned with earth landings in these categories and, in particular, with soft landings survivable by man. The areas of study are illustrated in figure 1. The velocity regions are (1) those having primarily vertical velocity,

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*This report was one of the papers presented at the NASA-Industry Apollo Technical Conference, Washington, D.C., July 18-20, 1961.

(2) those having both moderate horizontal and moderate vertical velocity, and (3) those having primarily horizontal velocity. The prime example of vertical velocity is the parachute letdown system. In its simplest application the parachute system would have vertical velocity only but in the more likely operational case the parachute letdown is complicated somewhat by the horizontal velocity that occurs with a landing in a wind or with a guided chute. Provisions must therefore be made for translation along the landing surface and for preventing dangerous turnover. The second area of study applies to the large and lightly loaded paraglider system which can have less vertical velocity
than the parachute (approaching zero), but must have horizontal veloc- L
ity and thus a slide-out capability. The third area encompasses high 1
horizontal velocity as associated with conventional airplane landings 7
and includes the high lift bodies, the winged space vehicles, and the 8
small and highly loaded paragliders. Vertical velocity is still a 2
design requirement but to much less a degree than in the first area. Runout performance is the most critical problem in this category.

DISCUSSION

A short motion-picture film supplement illustrating the effects discussed in this paper has been prepared and is available on loan. A request card form and a description of the film will be found at the back of this paper, on the page immediately preceding the abstract page.

Vertical Velocity Landings

The landing-impact energy dissipation for the various configurations depends on the vertical velocity V_V of the vehicle at contact, the stroke geometry of the system, and the usable energy of the dissipation material. The case of parachute letdown with vertical velocity only which lends itself to an analysis based on materials involved will be considered first. For comparison, the forces are vertical; there are no side forces. Figure 2 shows results from a weight study of several such energy dissipation systems. The energy dissipators investigated consist of braking rockets, gas-filled bags, frangible metal tubing, aluminum honeycomb, and balsa wood. The weight was determined by adding the dissipator weight and assumed dissipator attachment weight, but the parachute weight was not included. All these systems are familiar ones except perhaps the frangible tube. This is a system for working metal to its ultimate strength and through a large percentage of its length. An example of a frangible-tube installation could be a hard aluminum-alloy tube attached to a vehicle and a

die attached to a landing skid or foot. (See fig. 3.) The tube presses over the die during impact and fails in fragments as shown. Because of structural considerations, the gas bags, frangible tube, honeycomb, and balsa wood systems (fig. 2) are short-stroke devices and for low g application (10g is used here) are most suitable at contact velocities of the order of 20 to 40 feet per second. There is a practical limit on usable stroke with these devices so the data were not extended to higher speeds because of suspected buckling failure at the correspondingly higher strokes required. The braking rocket, shown by the dashed line, has completely different characteristics from the dissipators described and is more suitable at longer strokes and higher speeds. The data for the braking rocket are based on duration, thrust, and weight of actual rockets and include the weight of both propellant and rocket case. There is a large difference weightwise between the several systems, with the frangible tube, honeycomb, and balsa wood being the lightest at the lower speeds but not suitable at the higher speeds because of structural difficulties. The braking rocket is more suitable at the higher speeds. The adaptability of the systems to attachment, packaging, and environment must be considered when choosing a landing gear. For example, the gas bag, even though somewhat heavy, is very adaptable to packaging, whereas some of the lighter weight systems are bulky.

A photograph of a model of the L-2C vehicle having a frangible tube system installed between the capsule and what could be the heat shield is shown in figure 4. There are four tubular legs made of 2024-T3 aluminum alloy. A snubber cord is seen at the center of the model. The tubes on an actual installation would be made retractable, probably by pivoting. Figure 5 is a sequence photograph of a vertical landing of this model in which velocity at contact simulates 30 feet per second. The strut length was chosen so that about three-fourths of the length of the tube would be used up in the experiment. The fragments of the tube can be seen as they scatter.

An acceleration time history of this landing is shown in figure 6. The peak at the beginning of the experimental curve (dashed line) is a typical starting load which could be regulated by precrushing the end of the frangible tube instead of using a squared-off tube as in this case. The peak at the end of the curve is due to a combination of a rate effect and the falling off of the stopping load below that required for continued fragmentation. The computed curve (solid line) is based on a force of 40 percent of the yield value of the material. This average load is an arbitrary value dependent on the curvature of the die used. The 40-percent value is considered a good workable compromise between a die curvature that is too hard and one that is too soft. The rectangular shape of the time-history curve indicates an efficient use of stopping distance for the frangible-tube system.

Water landings are another very useful way of dissipating the energy of a vertical letdown system. There are several NASA reports available on the subject and, since the recommended shapes are well known, they will not be discussed here. (See refs. 1 to 3.)

Moderate Horizontal and Vertical Velocity Landings

The problems of moderate horizontal velocity V_h due to a wind during parachute letdown or in a landing of a large area paraglider have been investigated with models of several reentry vehicles. Vertical force can be dissipated in much the same way as previously discussed. A landing skid or some such device is required for horizontal translation, and horizontal force must be dissipated by friction. Skid shapes investigated have been those of the heat shields for the vehicles shown in figure 7. Shown here are vehicles having a flat bottom or skid with a turned-up bow, a spheroidal-shaped skid, and a longitudinal curved skid. Dynamic model investigations have been made with these vehicles with several energy dissipation systems. Landings were made on a smooth hard surface, on sand, and on water. The sand was not meant to represent any particular full-scale terrain but was chosen to simulate a landing surface with penetration characteristics between those of the smooth hard surface and water.

The following sequence photographs (figs. 8 to 12) of dynamic models illustrate the characteristic landing behavior for several vehicles and systems at moderate horizontal speeds. The first sequence (figs. 8 to 11) shows landings on hard-surface runways. Full-scale speeds are given.

Figure 8 shows the model with frangible tubes for load alleviation. Alinement links are used to take shear loads. The landing speed is 18 feet per second horizontal and 13 feet per second vertical.

Figure 9 shows a landing with a flat-bottom skid and multiple-air-bag load alleviators. Landing speed is 60 feet per second horizontal and 30 feet per second vertical. The bags are installed between the capsule and the heat shield. Since air bags cannot take shear loads, alinement links are used and the bags are angled forward.

Figure 10 shows a sand landing of the vehicle with a longitudinally curved bottom. Landing speed is 30 feet per second horizontal and 15 feet per second vertical.

Figure 11 illustrates a landing of the vehicle having a spheroidal-shaped bottom used as a skid-rocker whereby vertical energy is converted into a rocking oscillation. Horizontal velocity is 80 feet per second.

Vertical velocity is low. The oscillation is dissipated by a combination of friction force and aerodynamic damping and the curvature of the bottom regulates acceleration. The relationships of the center-of-gravity height to skid-rocker length determine whether the vehicle will overturn.

Shapes and sizes such as are generally associated with the heat shields of manned reentry vehicles will begin to skip from the water surface at speeds of about 80 feet per second as shown in the next sequence (fig. 12). Figure 12 shows that skipping was slight for the vehicle with a spheroidal-shaped bottom. The vehicle with the longitudinally curved bottom and the flat-bottomed vehicle made somewhat longer skips.

There is nothing particularly wrong with skipping in itself but, if the landing speed is very high, the conditions of subsequent impacts are unpredictable.

Examples of the results obtained in investigations of the type just described are given as follows. All values are full scale. Turnover characteristics for skid-rocker landings of the L-2C type of vehicle at horizontal velocities of 30 feet per second and 80 feet per second and a vertical velocity of 10 feet per second are presented in figure 13. Experimental model landings were made on a hard-surface runway at friction coefficients of about 0.35 to 0.45. The open points indicate stable landings and the closed points indicate turnover. Computed limits of stability for friction coefficients C_F of 0.35 and 0.45 are shown by the solid lines. An attitude range of about -40° to 15° is satisfactory for ratio of center-of-gravity height to base diameter of 0.2, for example. At a higher center-of-gravity location the attitude range is reduced as indicated by the data points and limit lines. However, these are fairly reasonable attitude ranges. Acceleration in the landings (not counting turnover) was very low, about 3 or 4g. Landings made on a softer surface such as sand or on a hard surface at a higher friction coefficient would show narrower limits for stability and thus would indicate that the rocker bottom concept is critical to friction coefficient. The equations of motion show that turnover is independent of change in horizontal velocity and this is substantiated by the model test for the range of touchdown speeds investigated.

Figure 14 shows data for landings with multiple air bags on the flat-bottom L-1 vehicle at a vertical velocity of 30 feet per second. The shape of the acceleration-time-history curves indicates the characteristic triangular pattern for the gas bag with a fairly low rate of application of acceleration. The dashed lines show experimental data; one curve is for zero horizontal velocity, and one for a horizontal velocity of 30 feet per second. The difference in acceleration is due

to an interaction through the drag link and the angular setting of the bags. A computed curve (solid line) for zero horizontal velocity shows good agreement with experiment.

Horizontal Velocity Landings

The third category, encompassing high horizontal speed as obtained with winged or lifting bodies, is primarily a condition of long runout; and runout behavior is the most critical problem. In this category special methods of load alleviation which are adaptable to the heat requirement of space vehicles and which offer weight savings over conventional wheel landing gear have been investigated.

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The following sequence photographs show some of the horizontal landing concepts which were investigated. Figure 15 shows a landing of a model of a winged reentry vehicle having an all-skid landing gear incorporating strain-strap shock absorbers. Landing speed is 185 feet per second. Directional stability is very good with this gear.

Figure 16(a) shows a skid-rocker landing at 150 feet per second for a lenticular-shaped lifting body having deployable tail panels for control and for flaring into a conventional piloted type of horizontal landing. (See ref. 4.) Water landings with the lenticular vehicle, however, presented greater problems than the hard-surface landings. (See fig. 16(b).) The model frequently made a second or third contact in an uncontrolled condition. Ditching aids were not effective in improving the water landings of this vehicle; therefore, some consideration was given to reducing the landing speed. Devices such as drogue chutes or braking rockets might be suitable if adequate control could be obtained. Figure 16(c) shows a water landing of the model at a horizontal speed about one-half of the normal landing speed. Skipping was appreciably reduced.

The water landing behavior at high speeds of the manned reentry bodies is not greatly changed by using a different bottom shape. This fact is illustrated in figure 17 with the flat-bottom L-1 vehicle at a speed of 130 feet per second. The landing simulates approach conditions resulting with a small highly loaded paraglider. Behavior was much the same as that of the curved bottom vehicle; however, the flat-bottom vehicle is susceptible to higher peak accelerations.

Shown in figure 18 is a sketch of the all-skid gear investigated on the winged vehicle. The gear incorporates energy dissipators of the strain-strap type in combination with landing skids. The strain strap is a replacable element which fails by plastic yielding and the skids

move aft and up. There is no bounce with such a gear. Questions have been raised concerning the landing runout stability of an all-skid gear but it has been found that a properly designed gear is directionally stable. In general, runout stability was satisfactory for landings at angles of roll and yaw up to 10°, the maximum investigated. The friction coefficient for the nose skid was 0.25 and for the main skid was 0.5 in these investigations. The difference in friction force between the front and rear skids is the major factor in the stability of the gear.

The peak normal and angular accelerations for the strain-strap energy dissipator on the winged vehicle are given in figure 19. The accelerations are relatively low, approximately 3g normal and 10 radians/sec^2 angular during landings at design sinking speeds of 4 to 12 feet per second. The data also show that the landing normal loads are constant with sinking speed as expected and computed for the strain-type energy dissipator as long as there is sufficient stroke.

Figure 20 shows acceleration time histories for a hard-surface landing of the lenticular vehicle. The sketches illustrate the rocking motion which converts the sinking speed energy into angular energy and stops the fall of the center of gravity as the vehicle rocks through 0° attitude. A small tail-skid shock absorber eases the vehicle onto the runway and very low acceleration occurs at initial contact. A maximum normal acceleration of about 5g occurs when the vehicle first rocks through 0°. Maximum angular acceleration of about ± 18 radians/sec^2 also occurs at this condition. The significant feature of this energy dissipation system is that, since the bottom of the vehicle serves as both a heat shield and as a skid rocker, only a small part of the weight of the vehicle is directly chargeable to the landing gear.

CONCLUDING REMARKS

It appears feasible to evaluate landing-gear systems for reentry vehicles by computational methods and free-body landing techniques with dynamic models. There are several ways of dealing with the vertical energy dissipation for an earth landing of such a vehicle. Some systems are more efficient than others, some package better than others, and a variety of promising systems are under study. Horizontal energy dissipation is simpler to deal with than vertical energy dissipation since translational friction is all that is involved; however, runout behavior becomes a factor. Vertical velocity can also be a big factor when high flight-path angles are associated with even moderate horizontal velocities. High-speed landings are particularly a problem, especially high-speed water landings and indications are that, if large

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Langley Research Center,
National Aeronautics and Space Administration,
Langley Air Force Base, Va., July 19, 1961.

REFERENCES

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2. Vaughan, Victor L., Jr.: Water-Landing Impact Accelerations for Three Models of Reentry Capsules. NASA TN D-145, 1959.

3. Vaughan, Victor L., Jr.: Landing Characteristics and Flotation Properties of a Reentry Capsule. NASA TN D-653, 1961.

4. Blanchard, Ulysse J.: Landing Characteristics of a Lenticular-Shaped Reentry Vehicle. NASA TN D-940, 1961.

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LANDING CONFIGURATIONS AND VELOCITY REGIONS

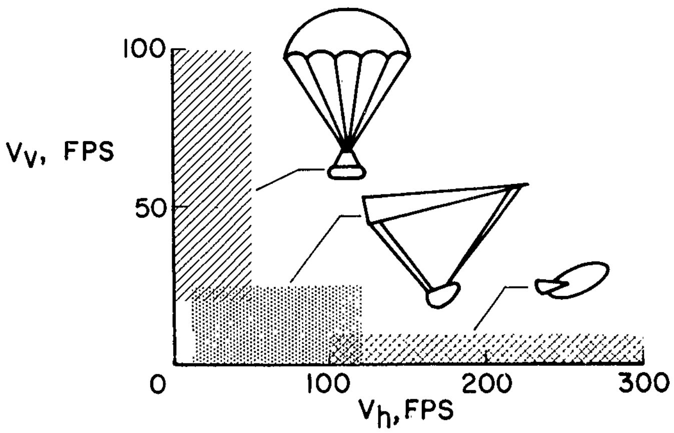

Figure 1

WEIGHTS OF LANDING SYSTEMS

VERTICAL DESCENT; 7,000 LB ; 10 g AVERAGE

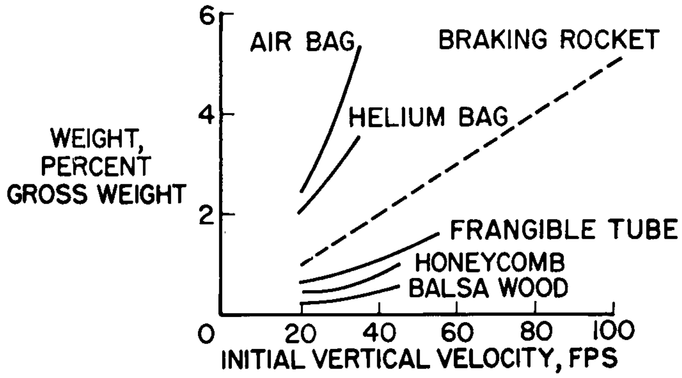

Figure 2

FRANGIBLE-TUBE SYSTEM

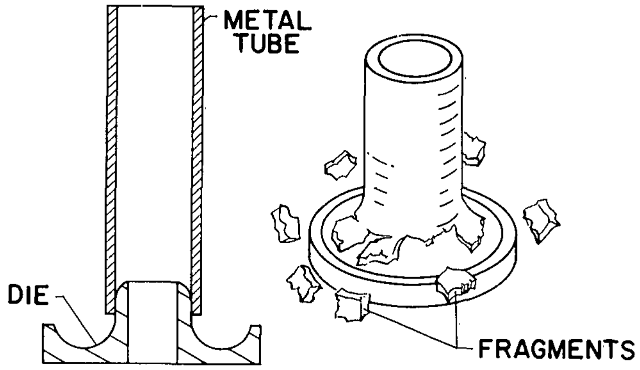

Figure 3

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MODEL WITH FRANGIBLE-TUBE LOAD ALLEVIATORS

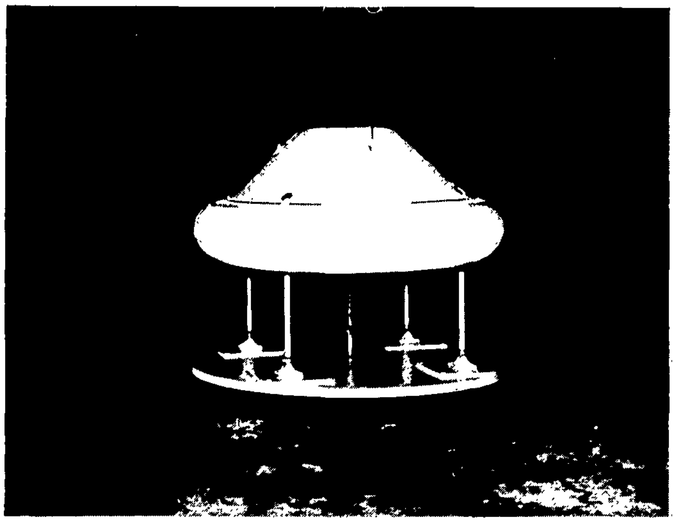

Figure 4 L-61-3475

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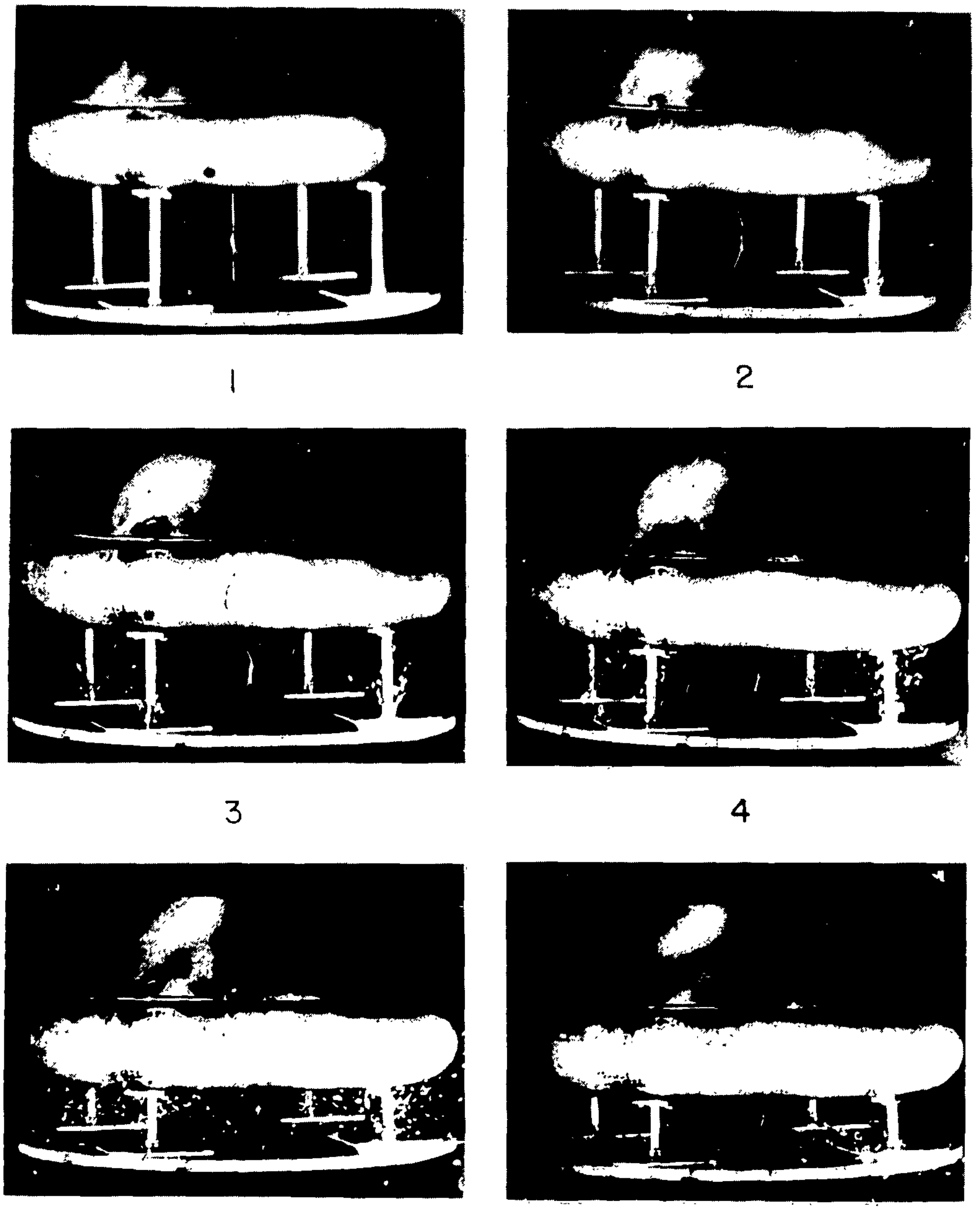
FRANGIBLE-TUBE MODEL LANDING ON CONCRETE
VERTICAL DESCENT; V_V = 30 FPS



1 2 3 4 5 6

Figure 5

L-61-4808

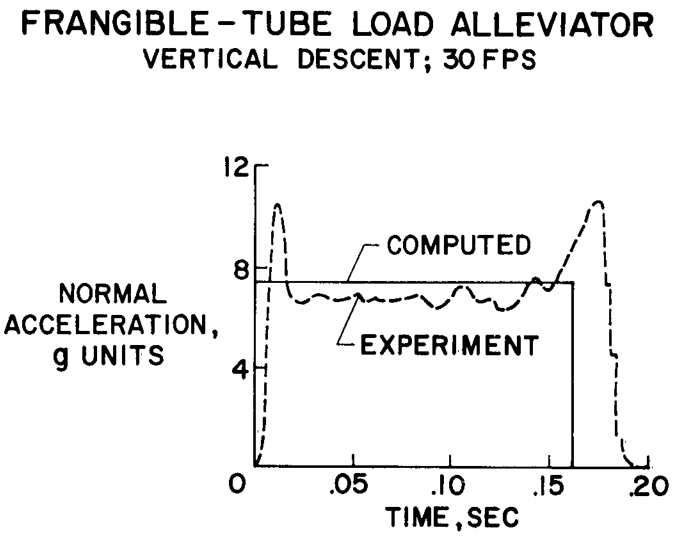


Figure 6

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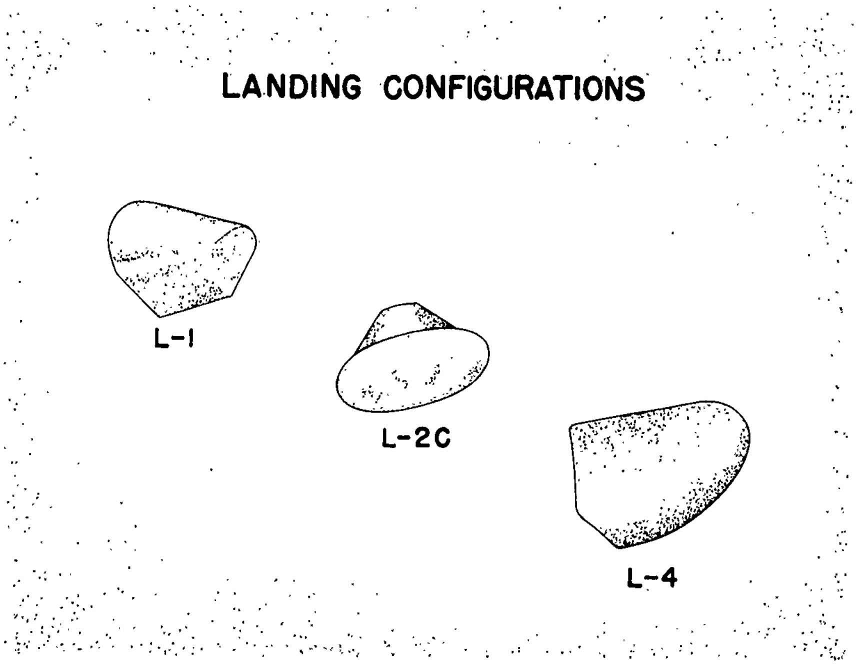
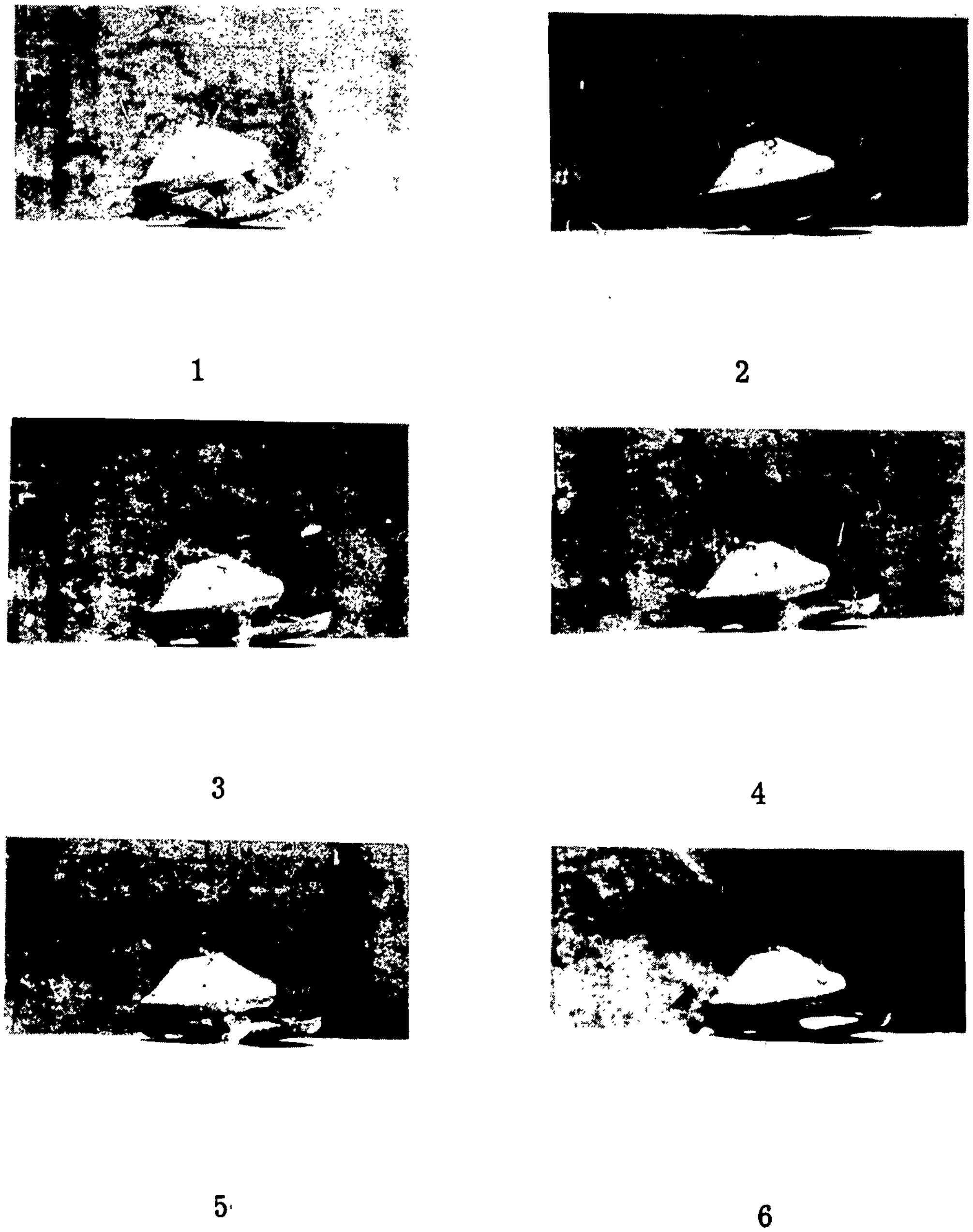


Figure 7

FRANGIBLE-TUBE MODEL LANDING ON CONCRETE
V_h = 18 FPS; V_v = 13 FPS



L-61-4813

Figure 8

MULTIPLE-AIR-BAG MODEL LANDING ON CONCRETE
V_h = 60 FPS; V_v = 30 FPS

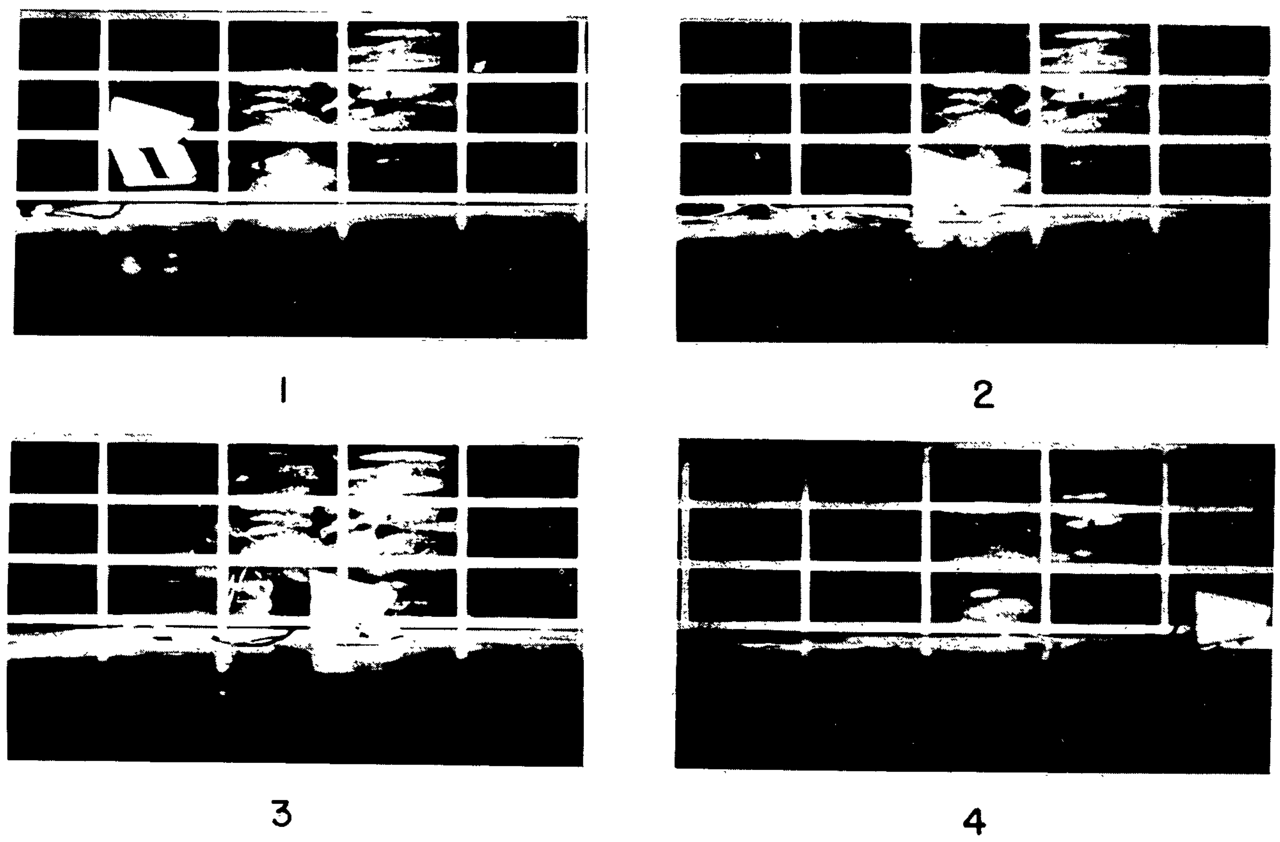


Figure 9

L-61-4812

L-4 MODEL LANDING ON SAND

$V_h = 30$ FPS; $V_v = 15$ FPS

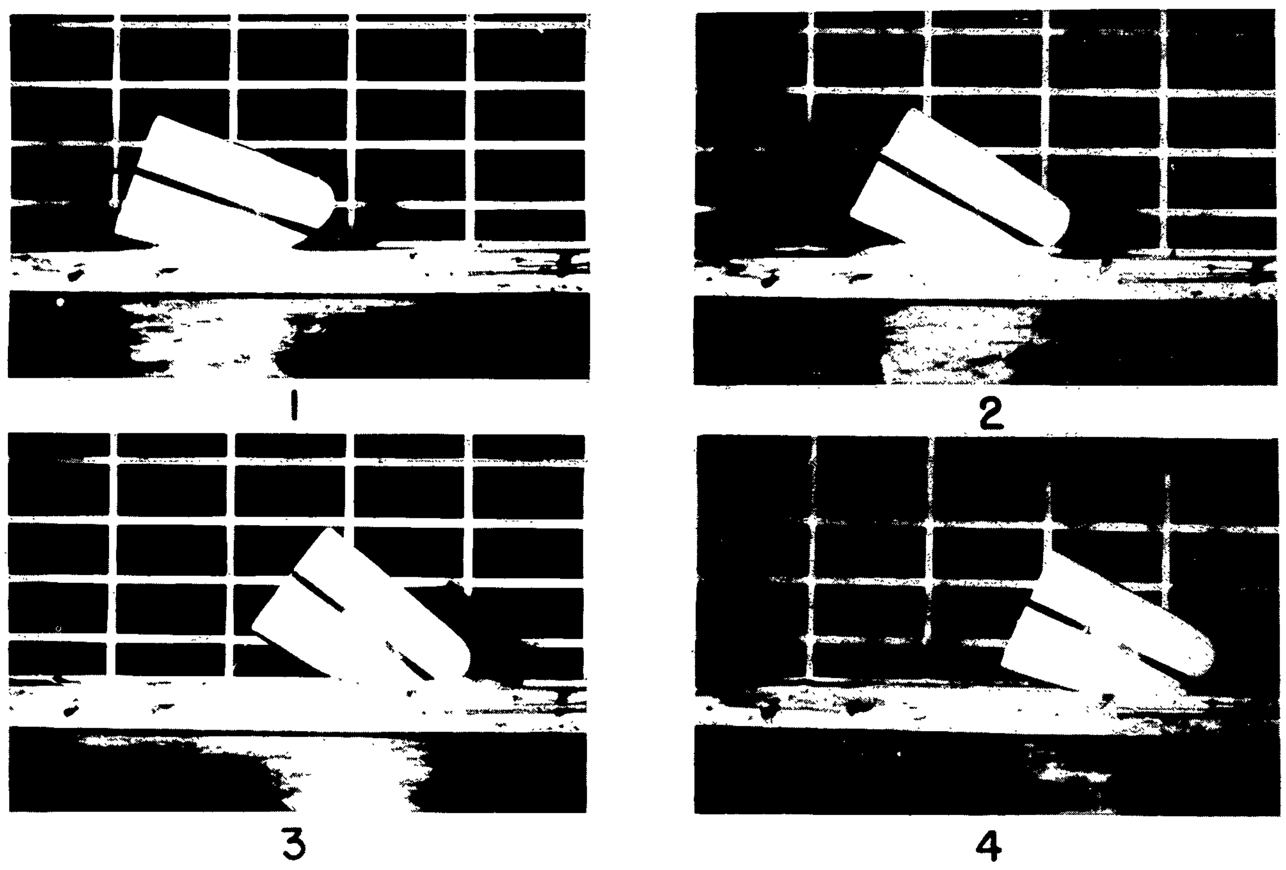


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Figure 10

L-2C MODEL LANDING ON HARD-SURFACE RUNWAY

$V_h = 80$ FPS; $\frac{\text{CENTER OF GRAVITY}}{\text{BASE DIAM.}} = 0.2$

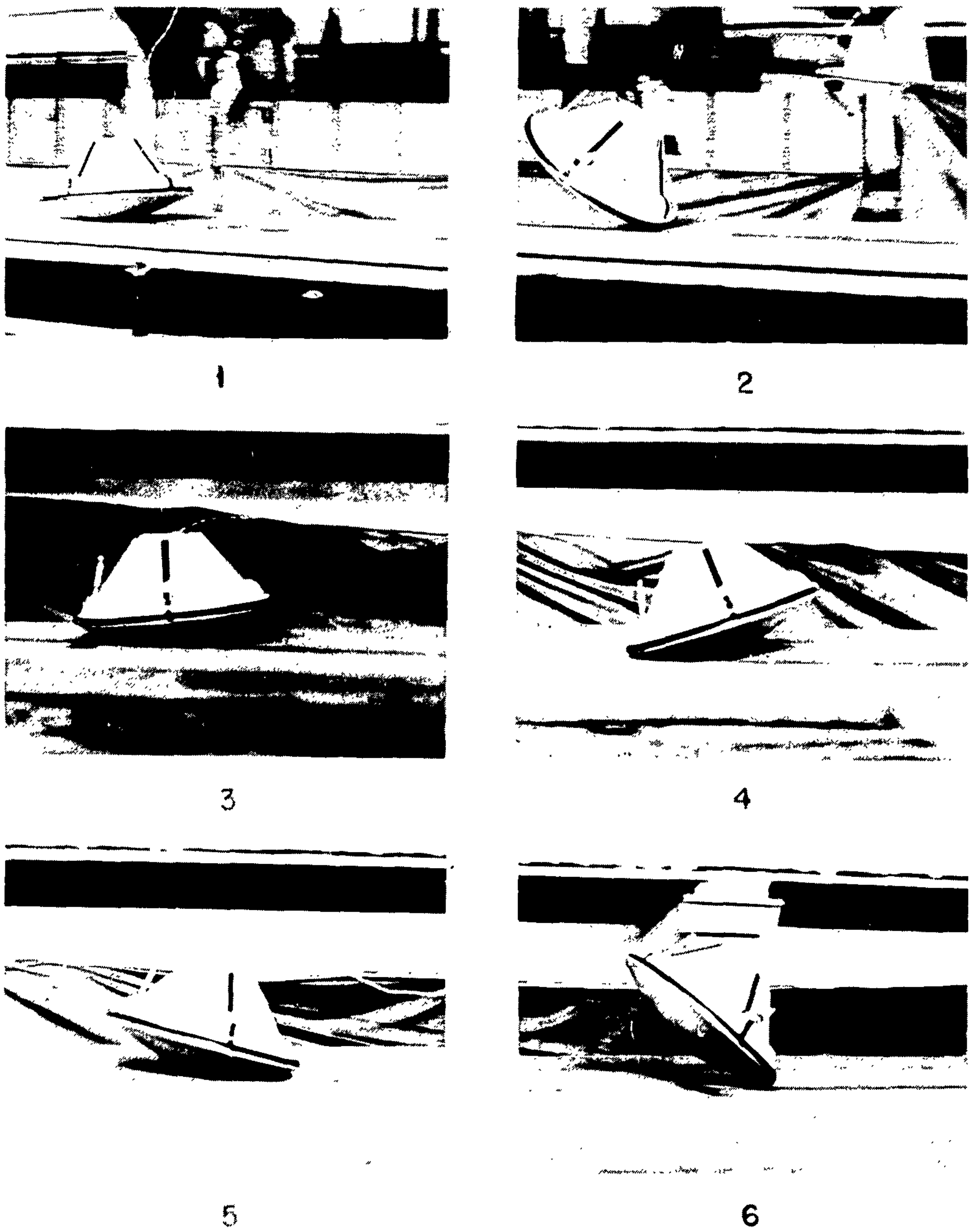

Figure 11 L-61-4811

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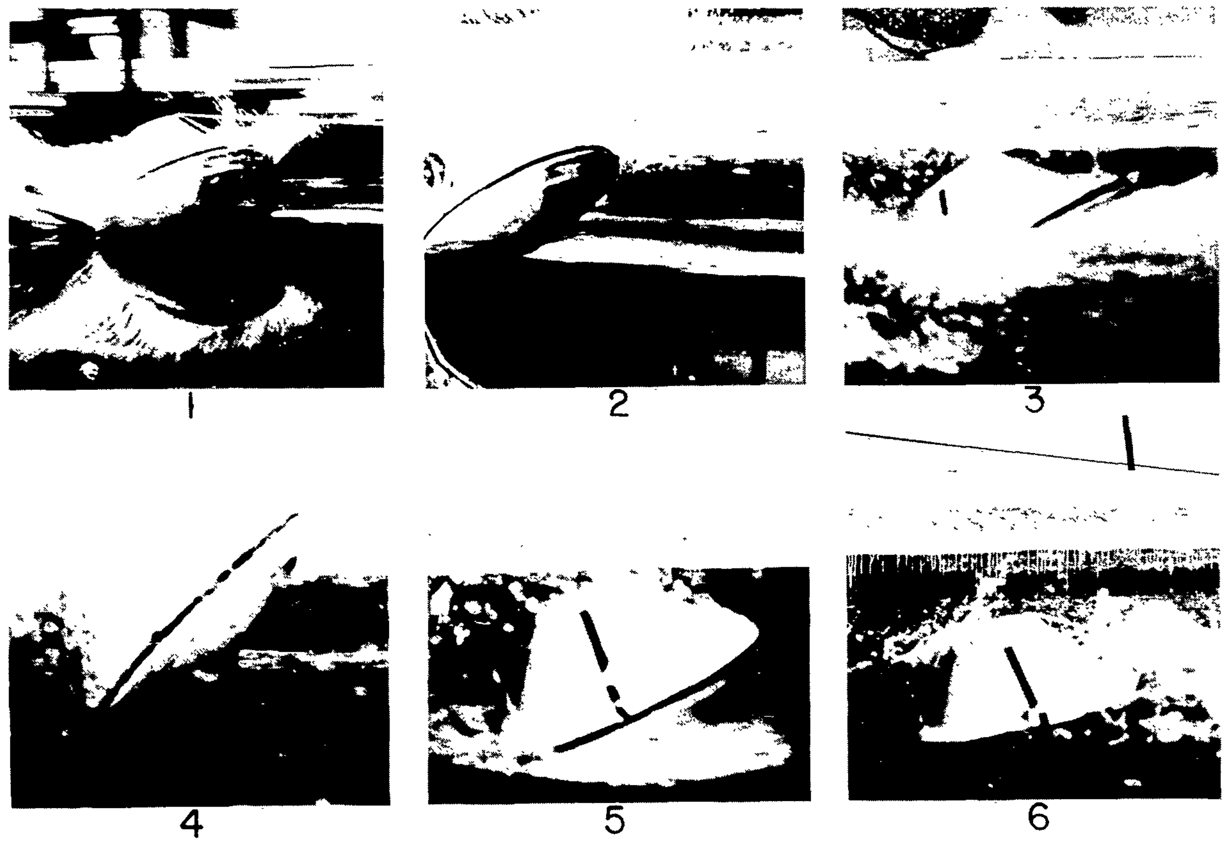
L-2C MODEL LANDING ON WATER

V_h = 80 FPS; V_v = 5 FPS



L-61-4810

Figure 12

TURNOVER CHARACTERISTICS FOR L-2C CONFIGURATION

HARD-SURFACE RUNWAY; V_V = 10 FPS

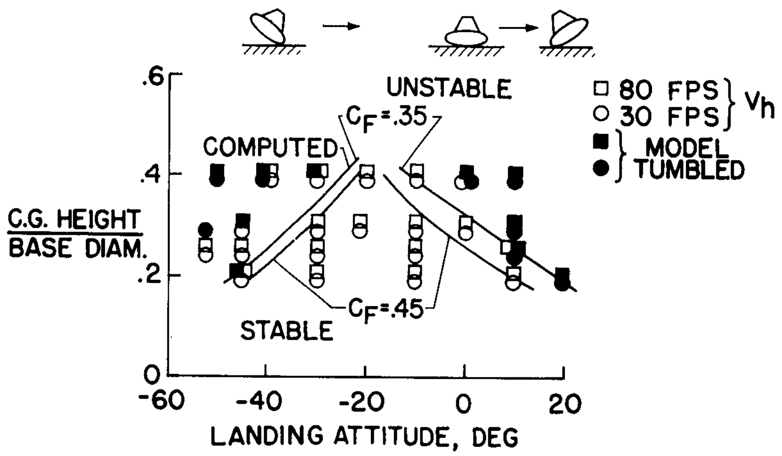


Figure 13

MULTIPLE-AIR-BAG LOAD ALLEVIATORS

V_V = 30 FPS

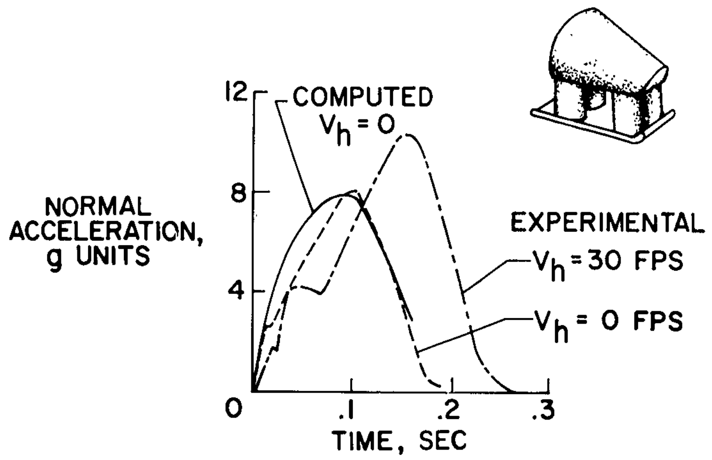


Figure 14

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TRAIN-STRAP MODEL LANDING ON HARD-SURFACE RUNWAY
V_h = 185 FPS

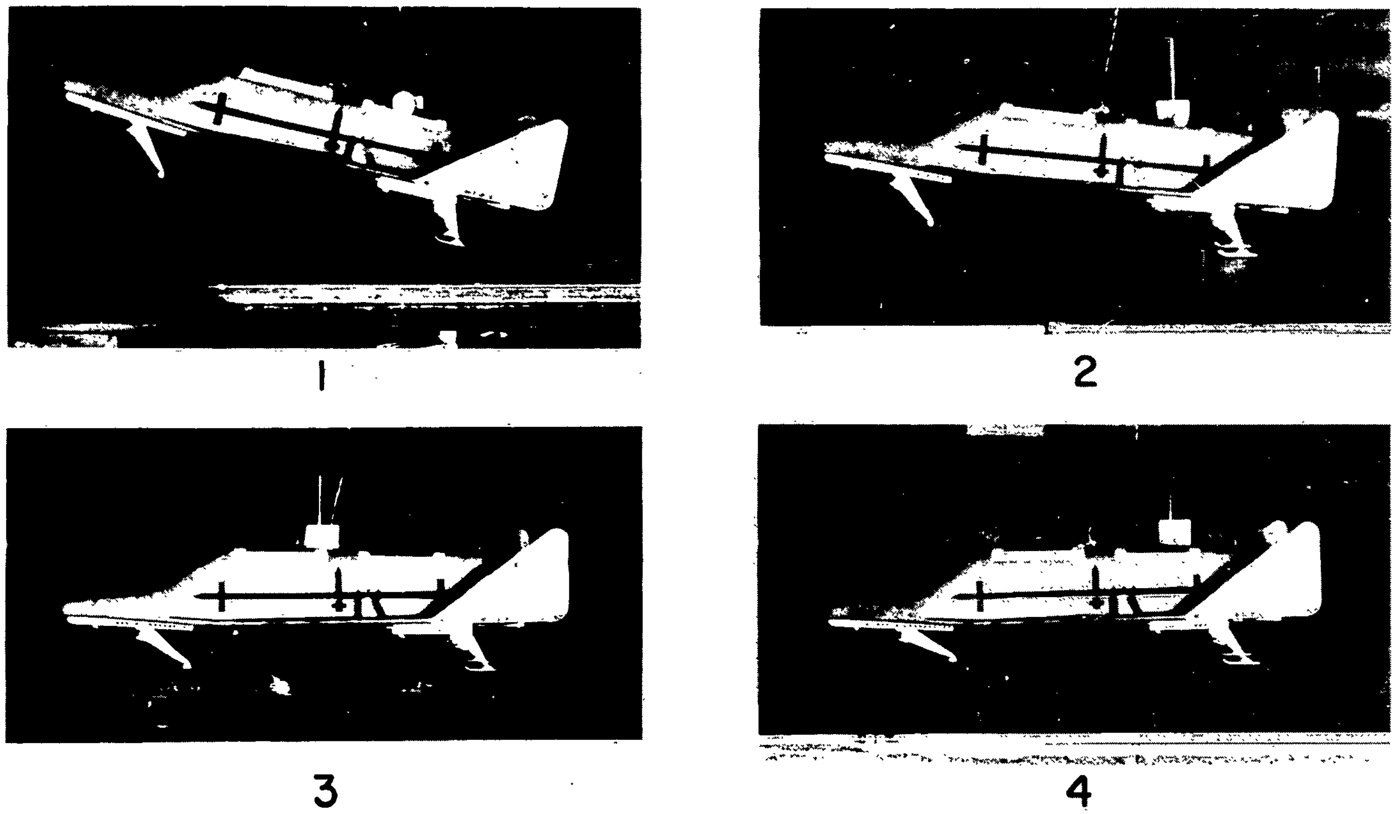

Figure 15

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LENTICULAR MODEL LANDING ON HARD-SURFACE RUNWAY
V_h = 150 FPS

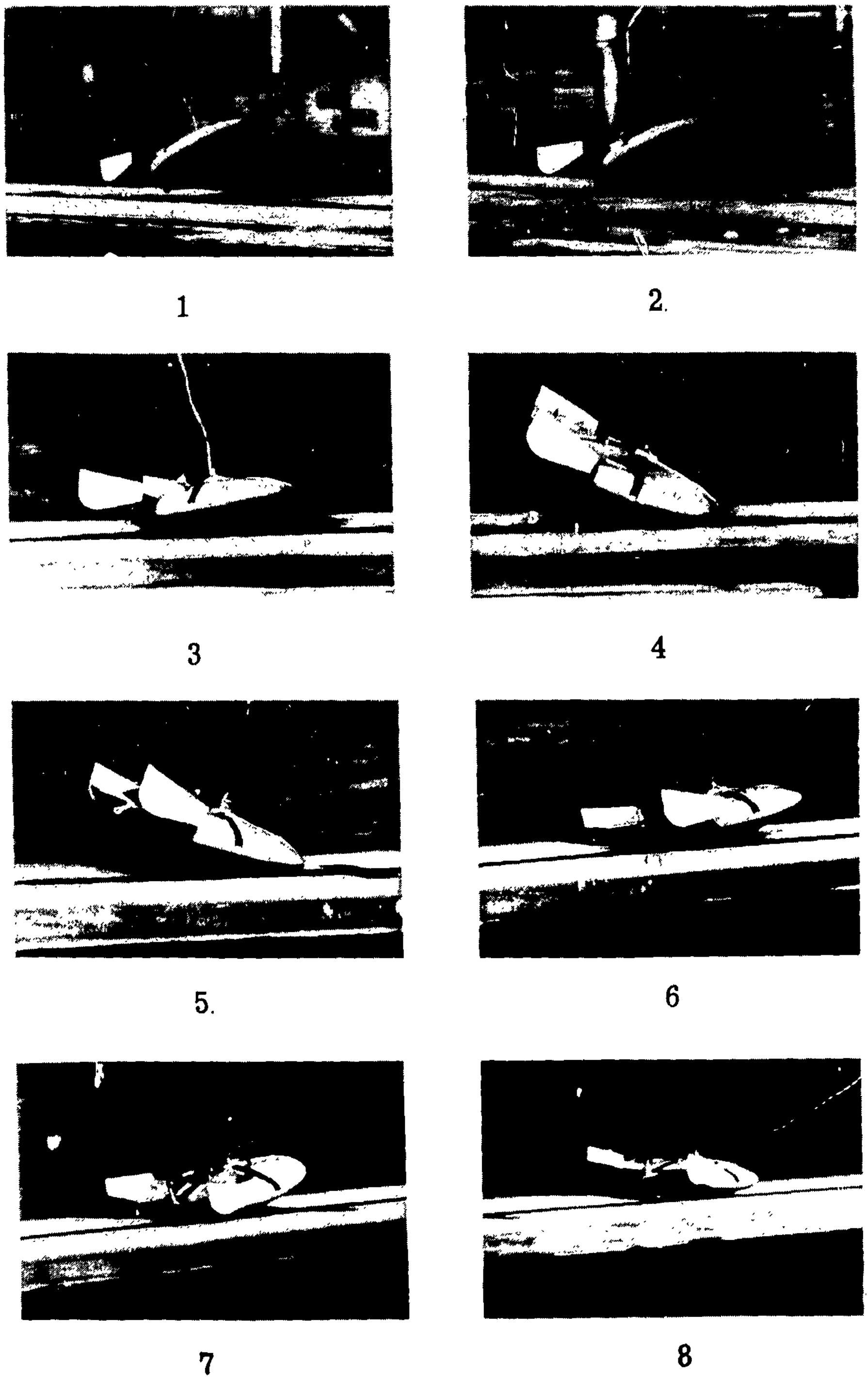

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Figure 16(a)

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LENTICULAR MODEL LANDING ON WATER
V_h = 135 FPS

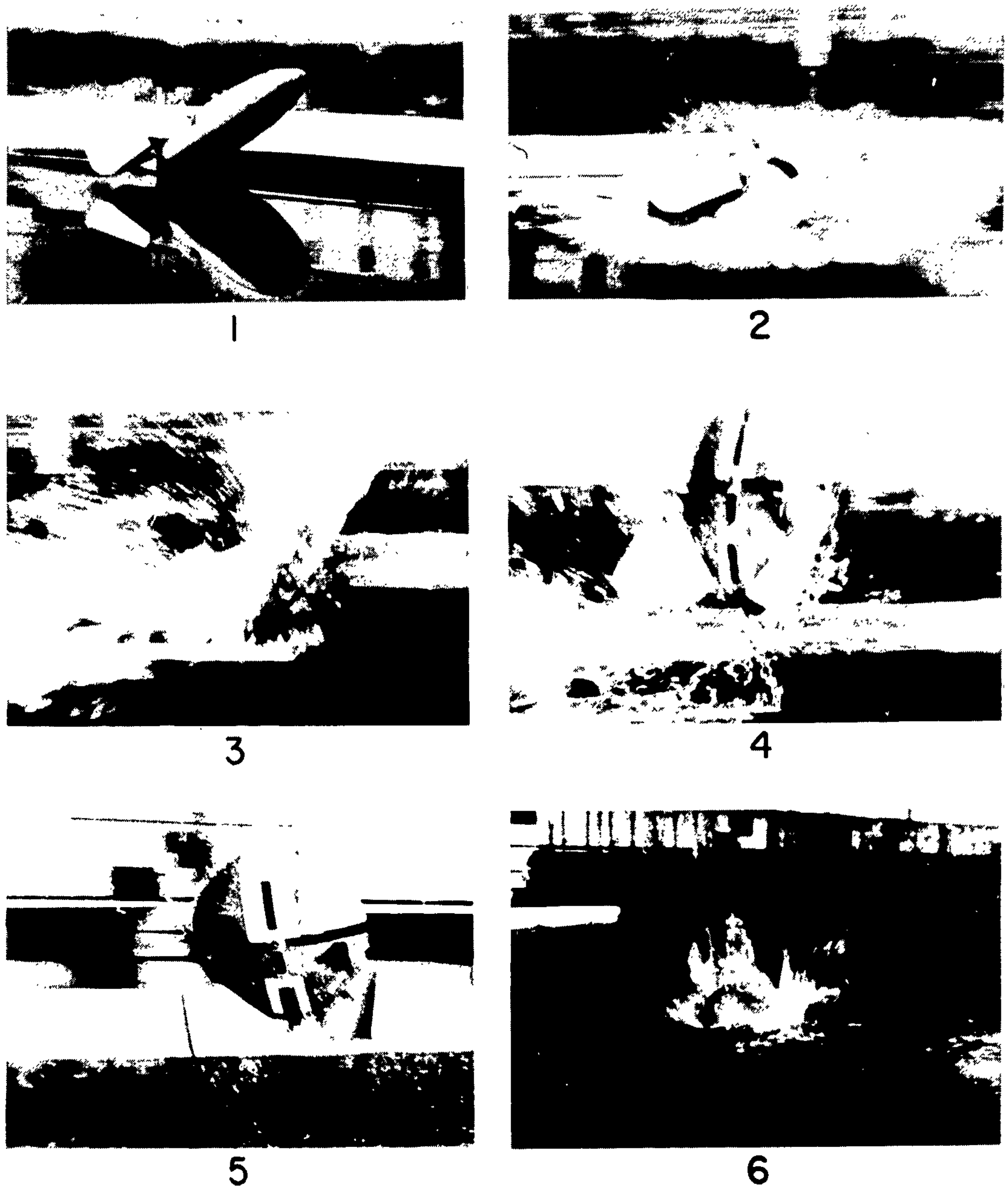

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Figure 16(b)

LENTICULAR MODEL LANDING ON WATER
V_h = 85 FPS

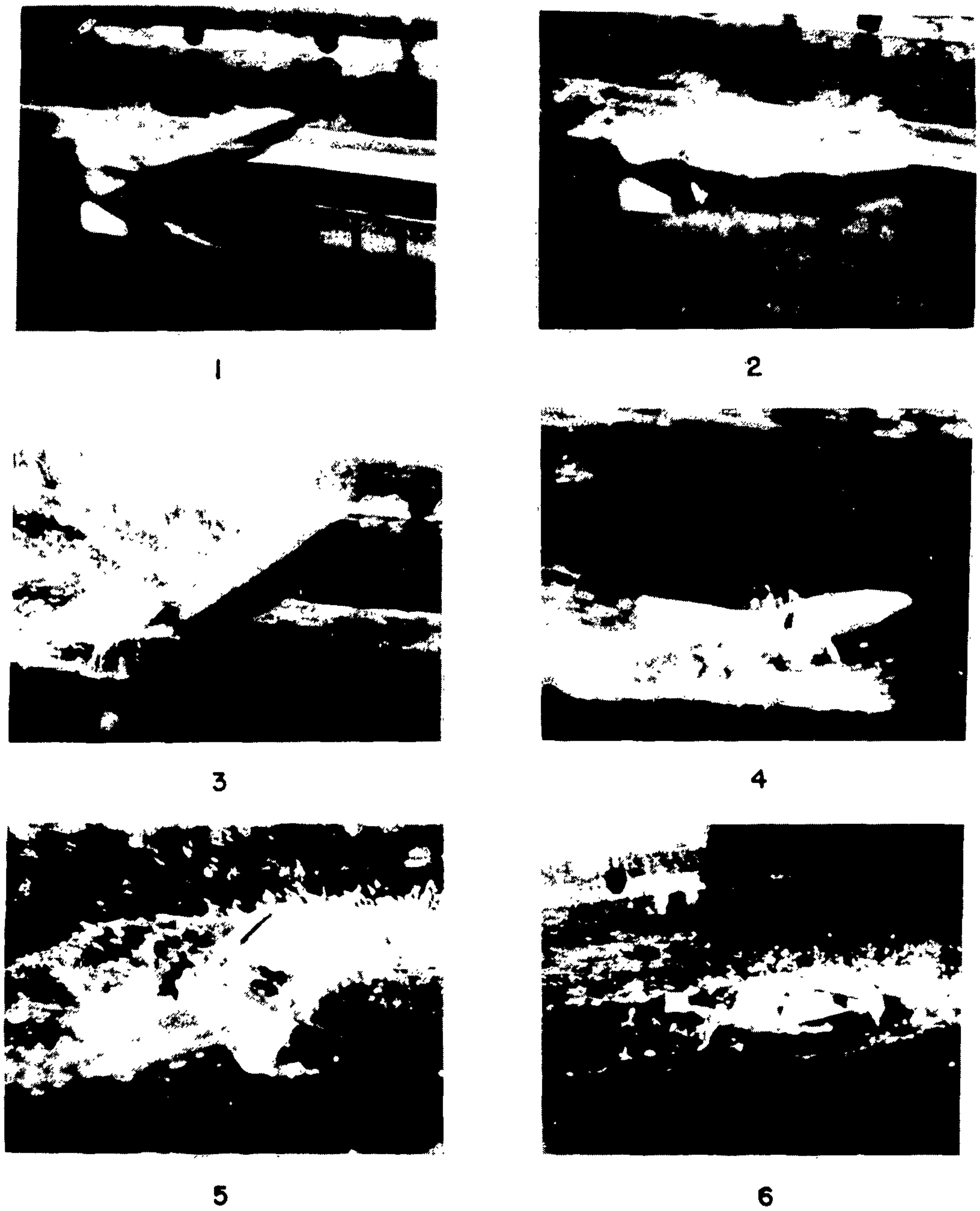

Figure 16(c) L-61-4807

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L-1 MODEL LANDING ON WATER
V_h = 130 FPS

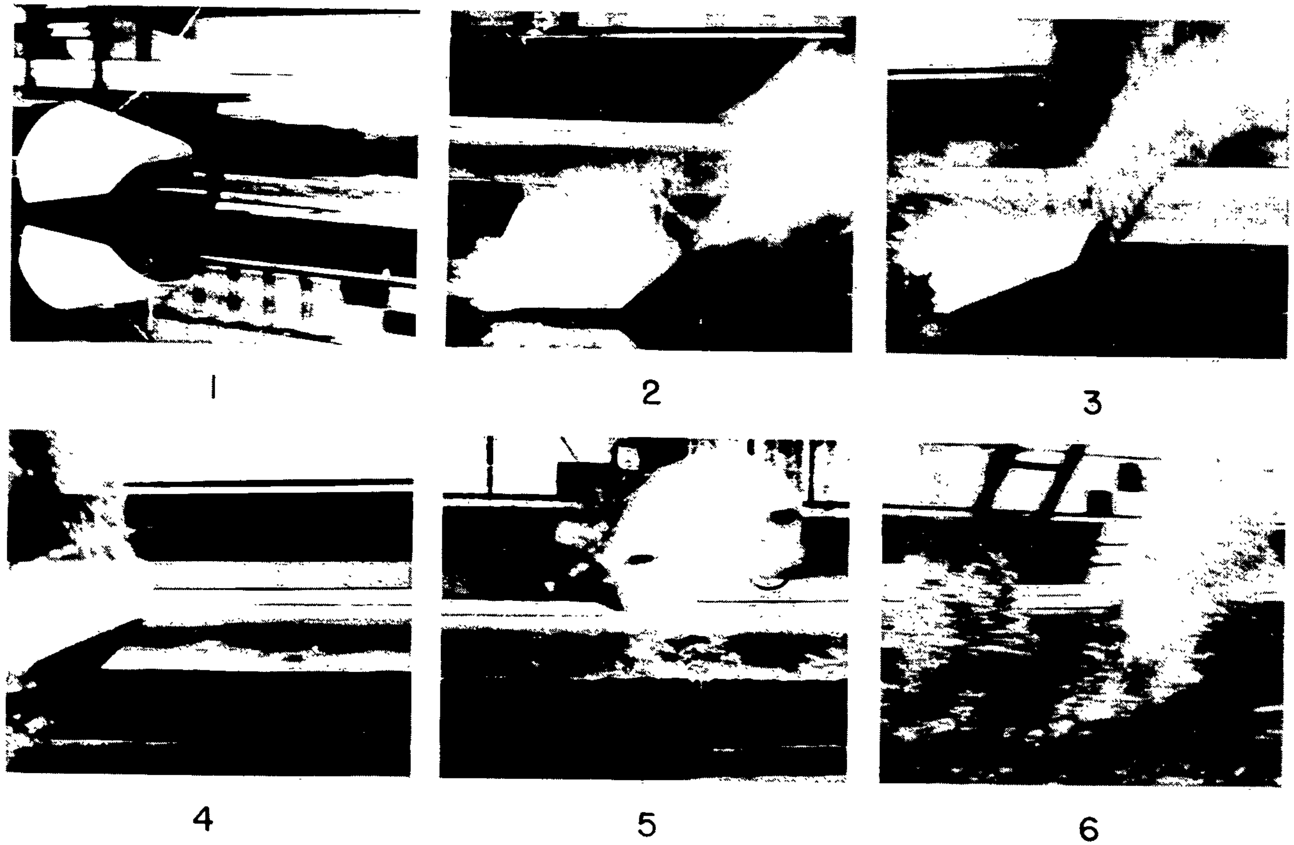

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Figure 17

LANDING GEAR COMPONENTS

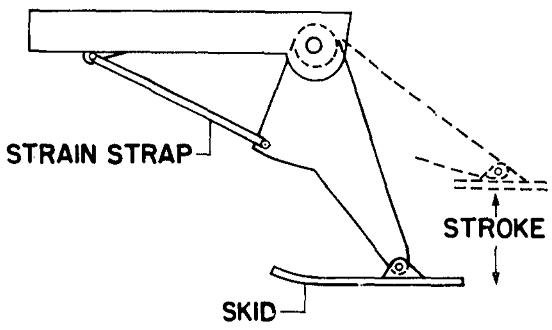

Figure 18

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STRAIN-STRAP LOAD ALLEVIATOR

V_h = 185 FPS; 8,000 LB; LANDING ATTITUDE, 15°

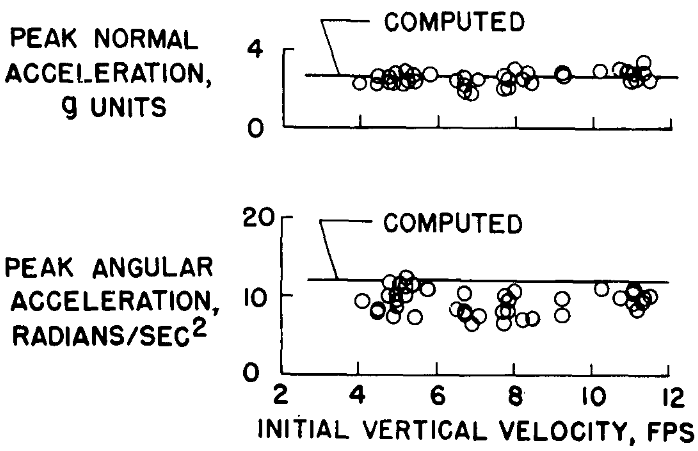

Figure 19

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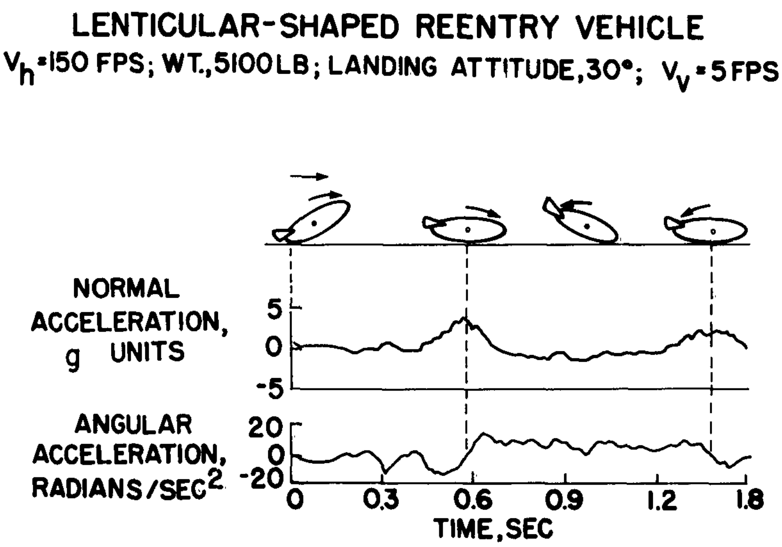

Figure 20

A motion-picture film supplement is available on loan. Requests will be filled in the order received. You will be notified of the approximate date scheduled.

The film (16 mm, 4 min, color, silent) shows dynamic model landings employing various impact-dissipation systems suitable for earth landings of reentry vehicles.

Requests for the film should be addressed to the

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LANDING-IMPACT-DISSIPATION SYSTEMS.
Lloyd J. Fisher, Jr. December 1961. 25p., film suppl. available on request. OTS price, $0.75.
(NASA TECHNICAL NOTE D-975)

Analytical and experimental investigations have been made to determine the landing-energy-dissipation characteristics for several types of earth-landing systems. Various ways of dealing with the vertical energy dissipation are presented. Horizontal energy dissipation is simpler to deal with than vertical energy dissipation since translation friction is all that is involved; however, runout behavior becomes a factor. Some feasible horizontal landing systems are demonstrated and discussed.

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Lloyd J. Fisher, Jr. December 1961. 25p., film suppl. available on request. OTS price, $0.75.
(NASA TECHNICAL NOTE D-975)

Analytical and experimental investigations have been made to determine the landing-energy-dissipation characteristics for several types of earth-landing systems. Various ways of dealing with the vertical energy dissipation are presented. Horizontal energy dissipation is simpler to deal with than vertical energy dissipation since translation friction is all that is involved; however, runout behavior becomes a factor. Some feasible horizontal landing systems are demonstrated and discussed.

Copies obtainable from NASA, Washington

I. Fisher, Lloyd J., Jr.
II. NASA TN D-975

(Initial NASA distribution: 52, Structures.)

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